Technical Document TRAC-TD-0196
April 1996

FORCE TAILORING TOOLS

TRADOC Analysis Center
Study and Analysis Center
Study Directorate
Fort Leavenworth, Kansas 66027-2345

Technical Document TRAC-TD-0196
April 1996

TRADOC Analysis Center - Study and Analysis Center
Study Directorate
Fort Leavenworth, Kansas 66027-2345

Force Tailoring Tools

REVIEWED BY:

DONALD W. KROENING
GM-15
Director, Study Directorate

APPROVED BY:

STEPHEN J. KIRIN
COL, FA
Director, TRAC-SAC

Distribution Statement:
Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1996

3. REPORT TYPE AND DATES COVERED
Technical Document, Jan 1994 - Apr 1996

4. TITLE AND SUBTITLE
Force Tailoring Tools

5. FUNDING NUMBERS

6. AUTHOR(S)
CPT Thomas M. Cioppa

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Study Directorate
TRADOC Analysis Center - Study and Analysis Center
ATTN: ATRC-SAS
Ft Leavenworth, KS 66027-2345

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Document
TRAC-TD-0196

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
TRADOC Analysis Center - Study and Analysis Center
ATTN: ATRC-SAS
Ft Leavenworth, KS 66027-2345

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Force Tailoring Tools are a tetrad of computer programs to assist both commanders and operations research analysts in designing force packages. The tetrad is composed of Force-PLUS (Force Package Logic Utility System), SCRAP (Sufficiency Criteria for Realignment Adjustment Processor), EFFORT (Early Entry Force Tailoring Tool), and THOR (The Task Organizer). These tailoring tools offer a marked departure from the traditional methods of designing force packages. Force-PLUS and SCRAP are used to analyze constructive simulation results. EFFORT's primary purpose is to give military planners and analysts at the strategic and operational level the ability to rapidly develop a tailored force package against a given threat and location. THOR's primary purpose is to give military planners and analysts at the operational and tactical level the ability to rapidly task-organize a force to accomplish its mission(s). The Force Tailoring Tools have been used in the Early Entry Force Analysis, Mobile Strike Force 95 Organizational and Operational Analysis, Battle Command Elective in the U.S. Army Command and General Staff College, and Warfighting Lens Analysis 98-12 Force Package Analysis.

14. SUBJECT TERMS force tailoring, simulations, fuzzy set theory, lethality, tempo, survivability, deployability, sustainability, Force XXI, linear programming, expert systems

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18

THIS PAGE INTENTIONALLY LEFT BLANK.

DISCLAIMER

The views, opinions, and/or findings contained in this paper do not reflect a final TRAC position and are not to be construed as an official Department of the Army policy or decision unless so designated by authorized documents issued and approved by the Department of the Army.

THIS PAGE INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The author of this document is indebted to the many people and organizations whose advice and cooperation made the origination of the Force Tailoring Tools possible. This included LTG John Miller, BG Geoffrey Miller, COL (Ret.) Allan Resnick, COL Thomas Pawlowski III, MAJ David Rodgers, Ms. Carol Mullen, Dr. Michael Anderson, Mr. Donald Kroening, TRADOC Early Entry Lethality and Survivability (EELS) Battle Laboratory, TRADOC Battle Laboratory Integration, Technology, and Concepts Directorate (BLITCD), Mr. Alexander Meeraus, and Mr. Peter Steacy.

THIS PAGE INTENTIONALLY LEFT BLANK.

ABSTRACT

The Force Tailoring Tools are a tetrad of computer programs to assist both commanders and operations research analysts in designing force packages. The tetrad is composed of Force-PLUS (Force Package Logic Utility System), SCRAP (Sufficiency Criteria for Realignment Adjustment Processor), EFFORT (Early Entry Force Tailoring Tool), and THOR (The Task Organizer). These tailoring tools offer a marked departure from the traditional methods of designing force packages. Force-PLUS and SCRAP are used to analyze constructive simulation results. EFFORT's primary purpose is to give military planners and analysts at the strategic and operational level the ability to rapidly develop a tailored force package against a given threat and location. THOR's primary purpose is to give military planners and analysts at the operational and tactical level the ability to rapidly task-organize a force to accomplish its mission(s). The Force Tailoring Tools have been used in the Early Entry Force Analysis, Mobile Strike Force 95 Organizational and Operational Analysis, Battle Command Elective in the U.S. Army Command and General Staff College, and Warfighting Lens Analysis 98-12 Force Package Analysis.

THIS PAGE INTENTIONALLY LEFT BLANK.

FORCE TAILORING TOOLS

1. **Purpose.** The Force Tailoring Tools are a tetrad of computer programs consisting of Force-PLUS (Force Package Logic Utility System), SCRAP (Sufficiency Criteria for Realignment Adjustment Processor), EFFORT (Early Entry Force Tailoring Tool)[1], and THOR (The Task Organizer). These tools have been used in multiple Training and Doctrine Command (TRADOC) Analysis Center (TRAC) studies; namely, Early Entry Force Analysis (EEFA), Mobile Strike Force 95 Organizational and Operational (MSF 95 O&O) Analysis, Battle Command Elective (BCE) of the U.S. Army Command and General Staff College (CGSC), and Warfighting Lens Analysis (WFLA) 98-12 Force Package Analysis. This technical document explains the Force Tailoring Tools and their integration into the various studies.

2. **Background.**

a. Force tailoring is a common, yet complex, problem for military planners and analysts. Determining the best force, both in terms of size and type, is important since it directly impacts on the success or failure of the force performing the mission. In the age of shrinking military budgets and expanding force projection, force tailoring is now even more critical. The forces deployed to different geographical regions must be capable of performing various critical wartime, as well as peacetime, tasks.

b. A lesson learned from Desert Shield and Desert Storm is that forces must deploy rapidly and still be both lethal and survivable. These early entry forces must arrive within a specified time (the Army Strategic Mobility Program specifies that the lead brigade arrive at C+4 and the lead division at C+12) and possess significant lethality and survivability characteristics. It is likely that future adversaries will not wait until the majority of our forces and infrastructure are present before initiating offensive operations.

c. TRADOC Pamphlet 525-71, *Force XXI Division Operations Concept*, recognizes that force tailoring is a critical factor for mission success in the 21st century. A prime characteristic of the Force XXI division is its rapid tailoring based on short-notice alert and METT-T (mission, enemy, troops, terrain and weather, and time available). Although the Force Tailoring Tools have mostly been used in the area of force design, they are relevant and applicable to force tailoring.

3. **Methodology comparison.**

a. *Old methodology*. The typical force tailoring process (old methodology) is to examine a series of pre-determined alternative force structures (usually two to four) by employing those forces in various combat models or simulations. A comparison of these forces against various issues and essential elements of analyses (EEA) is then done. The force which best satisfies the issues or EEA is deemed the "best" or objective force. A problem is that this force is the "best"

[1] Although called the Early Entry Force Tailoring Tool, the model is not limited to only early entry force packaging. The tool can be used for all force packaging requirements.

only among the selected alternatives for the particular set of conditions (e.g., weather, location, and threat) and assumptions (e.g., no chemical or nuclear usage, air superiority, and host nation support). It is doubtful that these particular set of conditions, assumptions, and circumstances will occur as specified. Furthermore, there may be other alternatives not examined that are better than the "best" determined by using the rigid alternatives. Does this imply that our current force design process is skewed? This is simply not so because the planner and analyst are able to gain insights into why the force performed the way it did. They can also determine more effective mixes of weapon systems and units, day versus night capabilities, chemical and nuclear environmental effects, and other force effectiveness measures. An alternate methodology, however, may be advantageous.

b. *New methodology*. The underlying concept of the Force Tailoring Tools development is that computer programs can be designed and used either to tailor the force after simulation analysis or prior to conducting the simulation.

(1) The tools are used to identify units (normally companies, batteries, and troops) which should be added or deleted from a force package to better satisfy the force package's goals. Instead of starting with predetermined alternatives (old methodology), a basecase force package forms the start point for the new methodology. Incremental changes (additions and deletions) are made to the force package to further improve achievement of the goals. This procedure is continued until all of the goals are accomplished or the force performance starts to decline. Figure 1 illustrates the two methodologies.

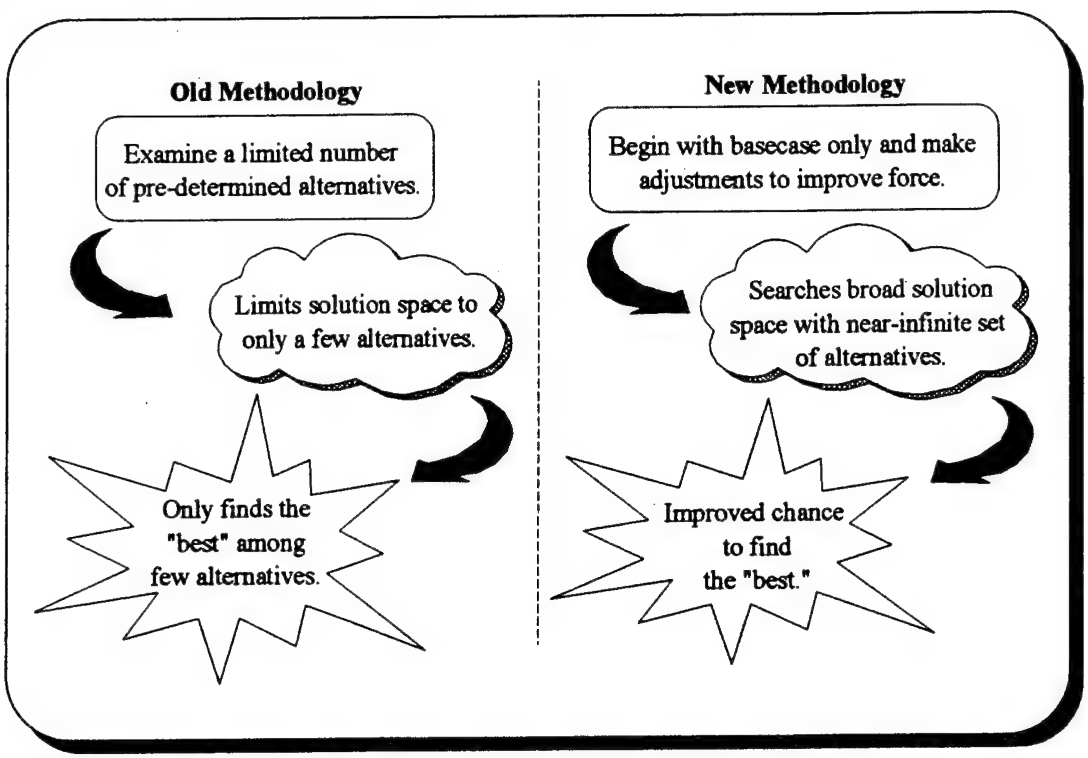


Figure 1. Old Methodology versus New Methodology

(2) Force-PLUS identifies units as possible additions that will improve the force's performance in simulations. SCRAP identifies units as possible deletions that do not contribute to force performance goals in simulations. These two tools are used in the new methodology to enhance the chance of finding the "best" force package. Force-PLUS and SCRAP allow the analyst to search a broad solution space instead of limiting the solution space to only a few alternatives. Force-PLUS and SCRAP are used in tandem with constructive simulations. The detailed explanations of these tools are in paragraphs 7 and 8.

(3) EFFORT can be used by military planners and analysts to determine the optimal force (includes combat, combat support (CS), and combat service support (CSS)) to deploy to a particular region to defeat a specific threat. The purpose of EFFORT is to give planners and analysts a more robust opportunity to identify the "best" force to deploy. It also allows decision makers the opportunity to examine "what-ifs," which are critical in identifying possible force shortfalls. EFFORT operates independently of Force-PLUS and SCRAP. A detailed explanation is in paragraph 9.

(4) THOR is designed for the operational and tactical commanders to assist them in the task-organization of their available force. The main difference between EFFORT and THOR is that EFFORT is used to determine the force package to deploy to a geographical region against a threat, whereas THOR is used to task-organize the force once it is deployed. THOR also operates independently of Force-PLUS and SCRAP; and can work in conjunction with EFFORT. EFFORT can identify the appropriate force package to deploy to a geographical region, and then THOR can be used to task-organize the deployed force. A detailed explanation of THOR is in paragraph 10. Figure 2 illustrates the hierarchy and layout of the Force Tailoring Tools.

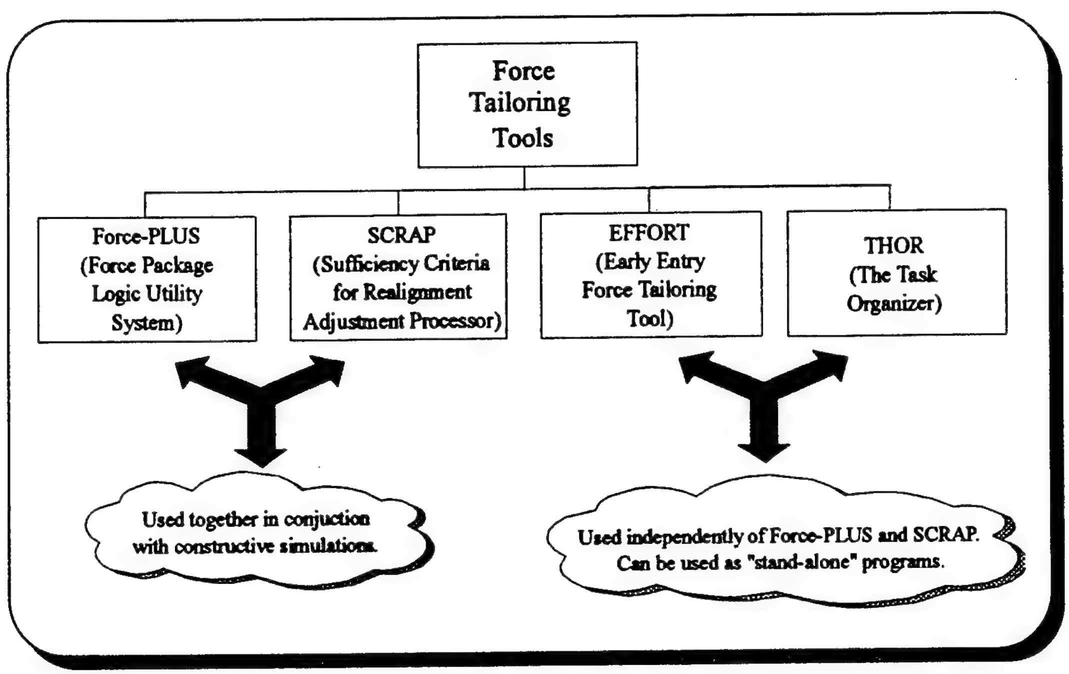


Figure 2. Force Tailoring Tools Overview

4. **Evolution.**

a. The Force Tailoring Tools originated with EEFA, the study conducted for the TRADOC Early Entry Lethality and Survivability (EELS) Battle Laboratory. EEFA's purpose was to examine the Louisiana Maneuvers (LAM) 1994 issue of how to make lightweight forces more lethal, survivable, sustainable, and tactically mobile, as well as how to make middleweight forces more deployable without losing tactical mobility or lethality. Force-PLUS and SCRAP were used in the tailoring process to arrive at optimal lightweight and middleweight force packages.

b. The Deputy Commanding General (DCG), TRADOC, believed the Force Tailoring Tools would be of benefit to the BCE Mobile Strike Force (MSF) Commander. The BCE MSF Commander recognized that, with modification, the tools could be of great use in helping to task-organize the MSF. EFFORT was restructured into THOR and was thereafter used in preparation for the Prairie Warrior 1995 (PW95) exercise.

c. Since the Force Tailoring Tools in EEFA proved highly successful, a similar approach was adopted for the MSF 95 O&O Analysis in support of the TRADOC Battle Laboratory Integration, Technology, and Concepts Directorate (BLITCD). The MSF was tailored using Force-PLUS and SCRAP. Instead of arriving at an overall objective force package as was done in EEFA, the MSF 95 O&O Analysis determined the distinct optimal force packages for the areas of lethality, survivability, and tempo. EFFORT and THOR were not used in this analysis.

d. EFFORT was used in support of Headquarters (HQ), TRADOC during WFLA 98-12 to determine if the warfighting capability differential of the force packages is increasing over time. This analysis examined the differences in capability among the four force packages in Northeast Asia (NEA) and Southwest Asia (SWA) for current (force year (FY) 1996), end of the program objective memorandum (POM) (FY 2003), and end of the extended planning period (EPP) (FY 2012).

e. Different elements of the Force Tailoring Tools were applied in each of the preceding efforts, depending on the particular study requirements. Figure 3 summarizes the evolution and use of these tools.

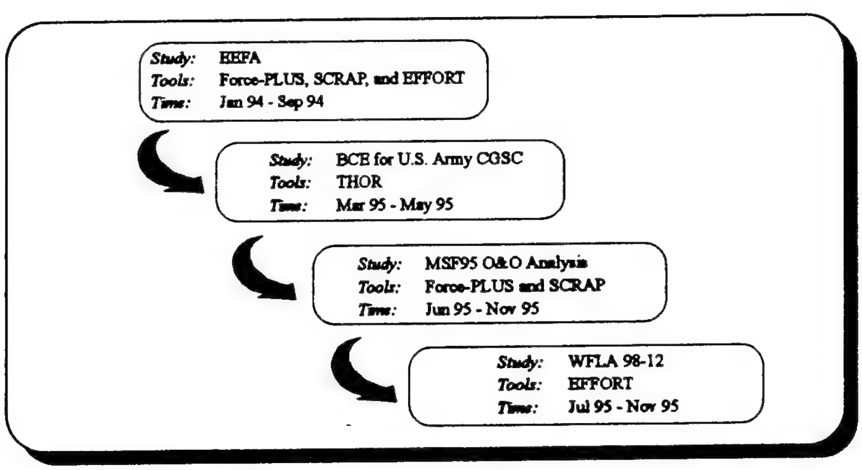


Figure 3. Force Tailoring Tools Evolution

5. **Warfighting characteristics and force sufficiency criteria.** Each of the computer programs uses warfighting characteristics and force sufficiency criteria (FSC), which are the fundamental building blocks in determining the goal accomplishments for the force packages. FSC are measured using both quantitative and qualitative methods.

a. Warfighting characteristics consist of the overarching principles of lethality, survivability, deployability, sustainability, and tempo. FSC are the particular subcomponents for each of the warfighting characteristics and are the desired goals for the force to accomplish. The FSC are composed of goals for the force to meet which subsequently allows an assessment of a unit's contribution to the success of the force in each of the warfighting characteristics. Achieving a goal indicates success; failure indicates the force has room to improve.

b. Figure 4 illustrates the various warfighting characteristics and FSC used in previous studies. Furthermore, additional and new FSC can be developed to suit the study requirements. The planner or analyst has the ability to change the desired level of goal accomplishment for the FSC. For example, for the FSC of destroying threat artillery under the warfighting characteristic of lethality, a user could specify success as destroying 50% (or whatever percentage will indicate success) of the threat artillery. The ability to change this percentage parameter (goal) permits sensitivity analysis.

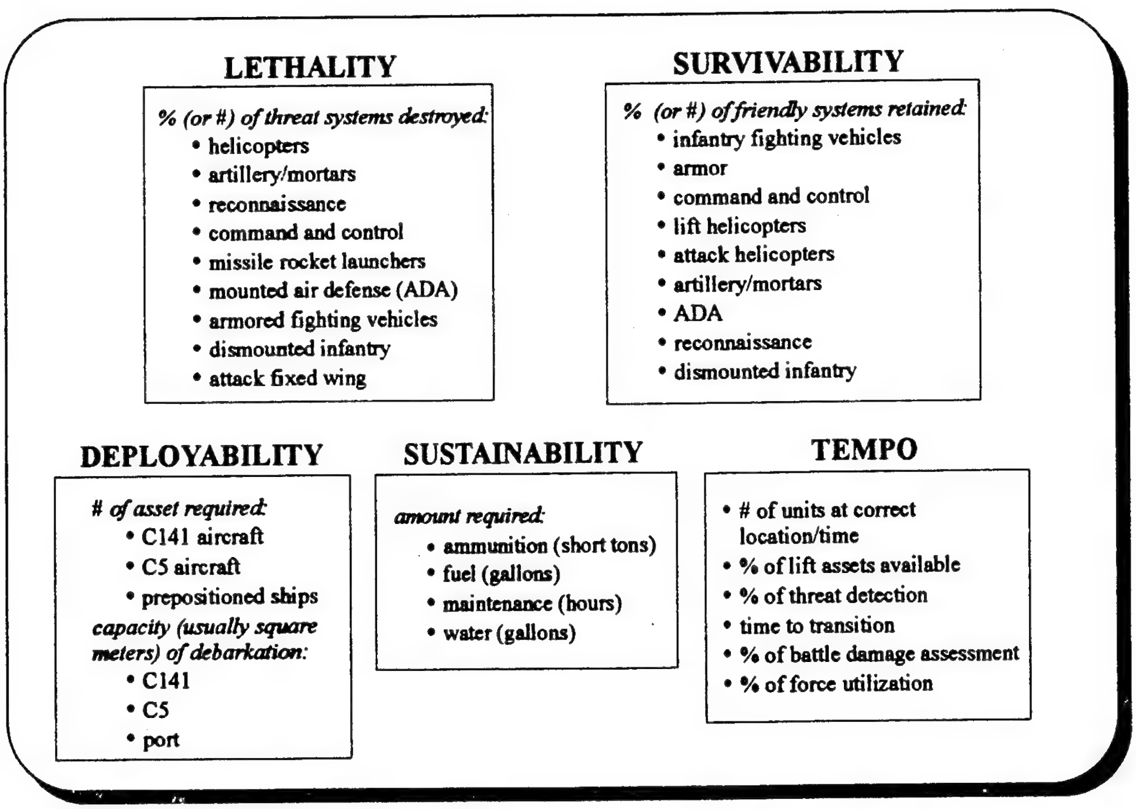


Figure 4. Warfighting Characteristics and Force Sufficiency Criteria

c. The user can choose the specified FSC applicable in a given study. Some or all of the FSC can be used depending on the requirement. For example, if a force was being developed to defeat

a threat that has no air attack capability, the FSC of destroying threat helicopters and attack fixed wing aircraft would not be relevant.

6. **Adjustment process basic concept.**[2]

a. FSC are identified for each warfighting characteristic of lethality, survivability, deployability, sustainability, and tempo. The warfighting characteristics are prioritized from the most to the least important. Weights are then assigned to represent relative importance, and the weight for each characteristic is divided among the FSC for that characteristic.

b. Combat analysis using a constructive simulation, deployment analysis using a deployability model, and sustainability analysis using supply usage data are conducted for each proposed force package. The results from these analyses are used in SCRAP to determine which units to consider for deletion. SCRAP calculates the deviation of the force's performance from the goals. It also computes the contribution of each type unit to this deviation. Force-PLUS uses input from subject-matter experts (SMEs) to assess the units in terms of the warfighting characteristics to determine which units to add. As a rule of thumb, no more than six types of units are added or deleted during each force adjustment. This keeps the adjustment process manageable by making controlled, incremental improvements rather than extensive changes to the force.

c. This process is iterative until force performance, as measured by SCRAP, starts to decline. This procedure improves the chances of finding a global optimum force package, instead of finding the best of a limited number of alternatives. Instead of examining a limited number of pre-defined alternatives, these tools (Force-PLUS and SCRAP) begin with only the basecase and move towards the optimal force package. If desired, the recommended (optimal) force package can be verified with EFFORT. Figure 5 depicts this process. Experience from previous studies suggests that no more than three iterations are required before the optimum is reached.

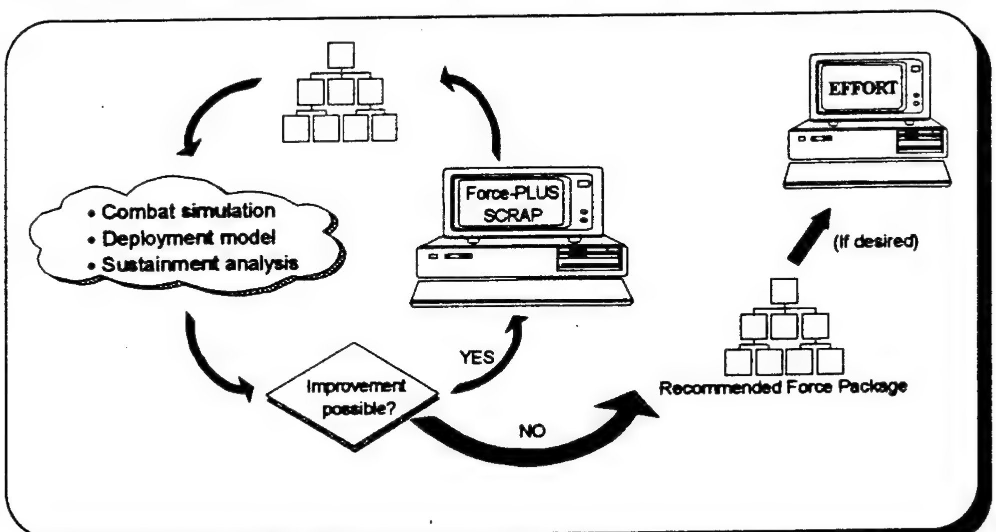


Figure 5. Adjustment Process Basic Concept

2 The author thanks COL Thomas J. Pawlowski III, Ph.D., MAJ David Rodgers, and Ms. Carol Mullen for their contributions in the methodology development and SCRAP.

7. **SCRAP.** SCRAP is a spreadsheet application (currently using the Lotus 1-2-3 software program) that determines a unit's (company, battery, or troop) contribution to the force's performance in a particular scenario. SCRAP is used to identify which units might be deleted from the force.

a. Force performance is measured by calculating the force's level of goal achievement, based on simulation results, for the FSC associated with each warfighting characteristic of lethality, survivability, deployability, sustainability, and tempo. A unit's contribution to force performance is calculated as a percent of deviation from each goal. SCRAP summarizes each unit's contribution to all goals to allow a comparison of overall unit contribution.

b. Units that make a poor contribution to the force's performance become candidates for deletion from the force. The units are candidates for deletion because military judgment is still a primary consideration in this process. Rather than automatically deleting units because of the SCRAP results, military judgment is the final determining factor. If SCRAP indicates that a light infantry company should be removed from the force, but military judgment dictates that the force only has the minimum number of light infantry companies present, then the decision is made not to delete that type of unit. No more than three types of units are deleted during any force package revision. The actual number of an individual unit type to delete is based on military judgment.

c. Since SCRAP relies heavily on combat constructive simulations for lethality results, sometimes only combat units (infantry, armor, artillery, air defense artillery, and aviation) are examined in SCRAP. However, CS and CSS units can be included in SCRAP since they do impact on the warfighting characteristics of survivability, deployability, sustainability, and tempo. In cases where CS and CSS units are not expected to destroy threat systems directly, and the analysis wants to consider these units, then no weight is given to the lethality FSC of these units. Instead only the applicable FSC are weighted.

d. The contributions from units of the same type are averaged together to determine the representative benefit of one given unit of that type. For example, assume there are two multiple-launch rocket system (MLRS) batteries in the force. If one MLRS battery destroys 50 threat armor vehicles, and the other MLRS battery destroys 70 threat armor vehicles, then the average of 60 is used to represent the contribution of an MLRS battery in destroying threat armor vehicles.

e. A sample calculation for deployability follows to clarify the SCRAP calculations.

(1) Assume, in this example, that the goal is to deploy the force in 900 planeloads and that the deployability FSC weight is .175.

(2) The force, however, currently requires 1,200 planeloads to deploy. Thus, there is a deviation from the goal of 300 planeloads, and this translates to be a percent deviation from goal of 33.3%.

(3) If a unit requires 10 planeloads to deploy, then by deleting it from the force, the force now requires 1,190 planeloads. This would represent a deviation of 290 planeloads and a percent deviation of 32.3% for the force. By deleting this unit, the force deployability would improve by 1.1%.

(4) The benefit gained by deleting the unit would be the percent improvement (1.1) to force deployability multiplied by the weight (.175) associated with this deployability FSC (+.001925). Figure 6 shows these calculations.

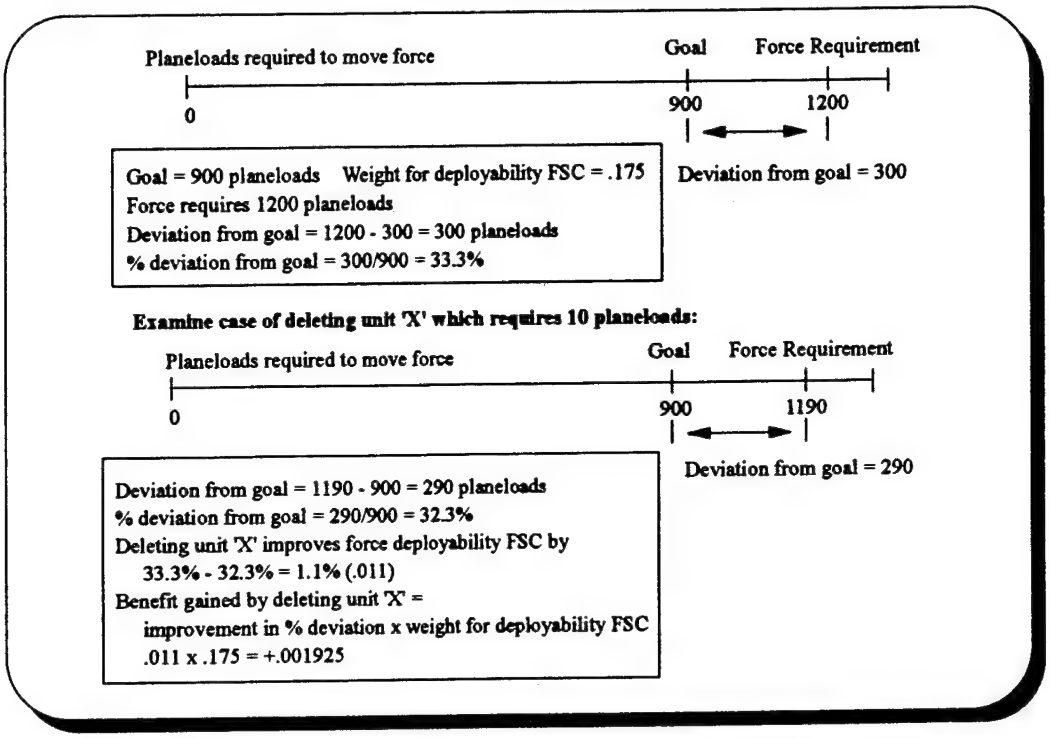


Figure 6. SCRAP Deployability Calculation

f. Similar calculations are made for each unit and FSC. The major difference in the lethality FSC calculations occurs when a unit does not kill any particular threat systems during the battle. In this case, a penalty is assessed to the unit for not having destroyed any systems that it should have. Only lethality FSC that clearly apply to the unit can have a penalty associated with it. For example, an Avenger battery would be expected to kill threat helicopters, so if an Avenger battery did not destroy any threat helicopters, it would be assessed a penalty. In contrast, an Avenger battery would not be expected to destroy threat tanks, so no penalty would be assessed to an Avenger battery because it did not destroy any threat tanks.

(1) The amount of penalty assessed is 10% of the total deviation associated with the force. The 10% was judged by military analysts as a reasonable amount of improvement which could be expected if the unit were making a valid contribution to the force effectiveness. Although this 10% was a judgment value, it worked well in the EEFA and MSF 95 O&O Analysis studies. If desired, the percentage can be changed depending on study considerations.

(2) A sample calculation for the lethality FSC for units making no contribution follows to clarify the process. Assume that the weight for the lethality FSC of destroying threat tanks is .025.

(a) Assume, in this example, a unit has not killed any threat tanks, but has the capability and is expected to kill threat tanks. The goal for destroying threat tanks is 70%, and the force actually achieved 52%. There is an 18% deviation from goal.

(b) The penalty assessed to the noncontributing unit is 1.8%, which is calculated by multiplying the penalty of 10% by the 18% deviation from goal.

(c) Deleting the unit from the force would improve the force's performance for this FSC by an estimated 2.57% (calculated by dividing the potential gain in lethality by removing the unit (1.8%) by the desired goal (70%)).

(d) When the 2.57% is multiplied by the weighting factor of .025, the benefit gained by deleting this unit is +.00064. Figure 7 depicts these calculations.

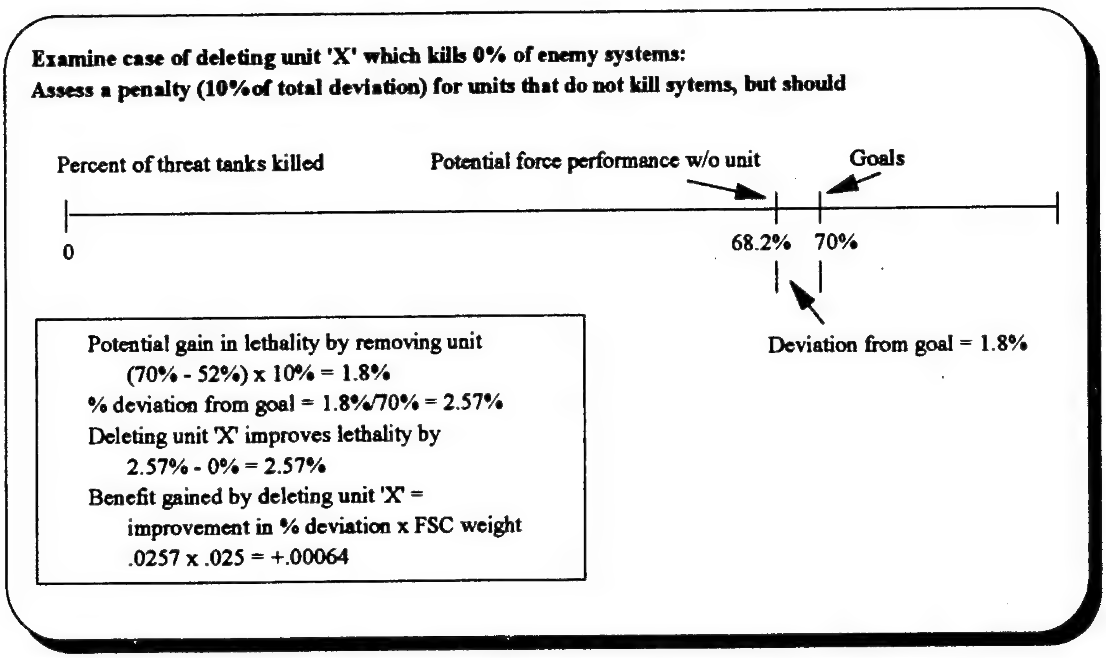


Figure 7. Lethality FSC Calculation with Penalty Assessment

g. Although the weighting factor assigned to each FSC is left to the discretion of the analyst depending on study considerations, the sum of the weighting factors for the FSC should add to one. For example, if the analyst determines that the lethality, survivability, and deployability FSC will each be weighted twice as much as the sustainability and tempo FSC, then the lethality FSC will divide equally the weight of .25, the survivability FSC will divide equally the weight of .25, the deployability FSC will divide equally the weight of .25, the sustainability FSC will divide equally the weight of .125, and the tempo FSC will divide equally the weight of .125. Figure 8

illustrates an example FSC weighting scheme adhering to the previous weighting of the warfighting characteristics.

	WEIGHTS
LETHALITY FSC	
destroy threat armor	.125
destroy threat artillery	.125
SURVIVABILITY FSC	
retain attack helicopters	.125
retain infantry fighting vehicles	.125
DEPLOYABILITY FSC	
deploy with prepositioned ships	.25
SUSTAINABILITY FSC	
amount of ammunition required	.0625
amount of fuel required	.0625
TEMPO FSC	
% of battle damage assessment	.125

Lethality weight of .25 distributed equally among lethality FSC

Survivability weight of .25 distributed equally among survivability FSC

Deployability weight of .25 allotted to sole deployability FSC

Sustainability weight of .125 distributed equally among sustainability FSC

Tempo weight of .125 allotted to sole tempo FSC

Figure 8. SCRAP Weighting Example

h. After all calculations are made to compute the benefit gained by deleting a unit for each FSC, these intermediate results are summed to determine the total benefit gained by deleting the unit.

(1) This value (the sum of all the FSC for a particular unit) is then multiplied by the total number of units of that type in the force package. For example, if the total of the FSC is .20 for the MLRS battery, and there are two MLRS batteries in the force, then the value for the MLRS batteries is .40.

(2) These values for the units are then rank ordered from highest value to lowest value. The units with the highest values are candidates for deletion. The actual number to delete of a particular type unit is determined by military judgment. For example, if the light infantry companies have the highest value from the SCRAP calculations, and there are six light infantry companies in the force, then military judgment and knowledge of the terrain and threat are used to determine how many, if any, light infantry companies should be deleted from the force.

i. Caution should be used when analyzing SCRAP results. Unit employment is an important factor in how units perform.

(1) For example, an M1 tank company is expected to destroy threat tanks and armored fighting vehicles (AFVs), but if the M1 tank company acts as the reserve for the force, then it may not contribute to the lethality FSC goals. Consequently, the SCRAP results may show that the M1 tank company is the primary unit type recommended for deletion, but knowledge of how the units were operationally employed is important to avoid incorrectly deleting such units.

(2) Two methods can be implemented to avoid incorrect unit deletion.

(a) The first method (preferred) is to not count units in SCRAP which are not directly involved. Assume that the force package has an M1 tank battalion (four companies). If three companies are in a movement to contact while the remaining company is part of the division reserve, then for the SCRAP calculations, only three companies should be counted instead of four.

(b) The second method relies on military judgment in unit assessment. If the analyst finds that a unit type is the primary candidate for deletion, but recognizes that the unit type's performance was based more on operational employment instead of actual performance, then the analyst can ignore SCRAP's recommendation.

j. In summary, SCRAP is used with constructive simulation results to determine which unit types did not contribute to the accomplishment of the force's goals. This spreadsheet tool offers analysts a more objective method for determining which unit types can be deleted from a force package.

8. **Force-PLUS.** Force-PLUS is an expert system capturing subject-matter expertise and uses the C Language Integrated Production System (CLIPS)[3] to determine which units to add to a force package to improve its mission accomplishment. Although CLIPS is used as the programming tool, any data base system could be used to categorize and search for units.

a. The main purpose of Force-PLUS is to help eliminate biases and parochialism in selecting units to add to the force. Instead of choosing units to add to a force based on preconceived bias, the expert data base allows the user to search for units that can enhance force performance in its poorest performing areas. When using Force-PLUS to determine which units to add to a force package, no more than three unit types are added during an iteration.

b. Unit assessment is done using an ordinal scale. Qualitative assessments are used because quantitatively assessing the units would be a more difficult and time consuming task. Units are assigned membership in one of five sets (significance levels) for each FSC. The order of the unit types in each set is unimportant. However, the unit types in the first set are better in the capability than the unit types in the second set, which, in turn, are better in the capability than the unit types in the third set, etc.

---

[3] CLIPS is an expert system developed by the Software Technology Branch, NASA/Lyndon B. Johnson Space Center. CLIPS is designed to facilitate the development of software to model human knowledge or expertise.

c. The data base includes each type of company, battery, and troop which can contribute to the attainment of the force's goals. The unit capabilities are assessed in the warfighting characteristics of lethality, survivability, deployability, sustainability, and tempo. Force-PLUS offers an easily expandable data base which can be adapted to incorporate different warfighting characteristics and FSC.

(1) For each of the FSC pertaining to the warfighting characteristics, each unit is given a significance level of *1* to *5* (where *1* is best) for its ability to improve an FSC.

(2) The guideline used in assigning a significance level is to attempt to have equal numbers of units assigned to each of the significance level categories.

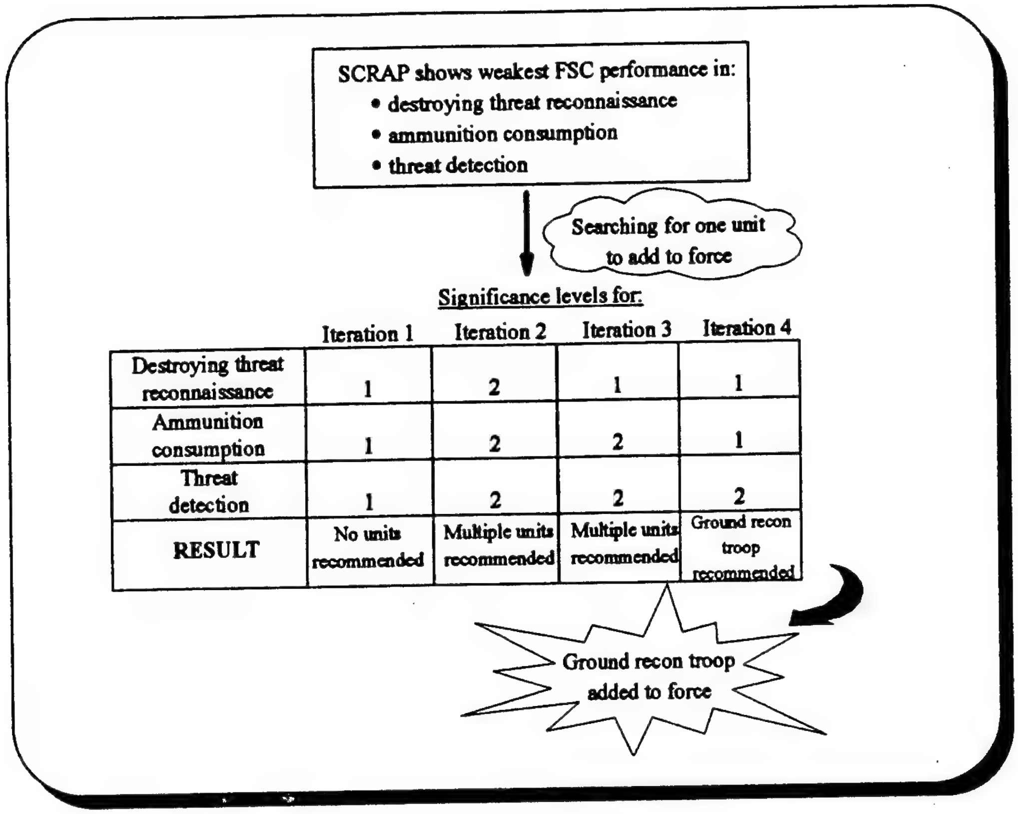
(a) For example, if there are 30 units in a force and the tempo FSC of conducting battle damage assessment is being examined, the analyst (given input from SMEs and previous constructive simulation results) would attempt to place six units in each significance level category.

(b) This guideline cannot always be followed. For example, only a few units can and are expected to destroy threat helicopters. The majority of units do not have this capability so these units would receive a significance level of *5*.

d. The analyst can search for units in Force-PLUS that improve the FSC where the force performed poorly. From the SCRAP analysis, the user can determine where the force was furthest away from its FSC goals and then search for units that will contribute to these FSC.

(1) If no unit is identified by Force-PLUS, then the user must relax the significance levels. Conversely, if many units are given from Force-PLUS, then the user can tighten the significance levels.

(2) An example best demonstrates these principles. If there are three FSC where the force requires better performance, the analyst searches for units which have a significance level of *1* in all these areas. If no unit is returned, the user relaxes the significance level to *2* (either for one, two, or all three FSC) and again searches the units. This process is continued until a unit is identified. If many units are identified, the user can tighten the significance levels of certain FSC until only one unit is recommended. The analyst, using military judgment, then decides how many of that particular unit type to add to the force package. Figure 9 illustrates this procedure.



	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Destroying threat reconnaissance	1	2	1	1
Ammunition consumption	1	2	2	1
Threat detection	1	2	2	2
RESULT	No units recommended	Multiple units recommended	Multiple units recommended	Ground recon troop recommended

Figure 9. Force-PLUS Example

e. The data base for Force-PLUS is easily expandable to incorporate other FSC, especially for qualitative type assessments. For example, although quantitatively deriving unit data for the effect of digitization on force improvement is difficult, the qualitative significance levels assigned by SMEs can more readily provide a meaningful index. Furthermore, the significance levels can easily be revised to reflect changes in SME thinking.

f. In summary, Force-PLUS can be used to determine which unit types should be added to enhance a force package's attainment of goals. When used in conjunction with SCRAP, these two tools offer an increasingly objective method in making iterative improvements to a force package.

9. **EFFORT.** The U.S. Army wants their forces to be highly lethal and survivable, but at what cost to sustainment and deployability? Typically, as highly lethal units are added to a force package, the force deployment and sustainment burden increases. This dilemma of conflicting goals and tradeoffs indicates the potential usefulness of a goal programming approach. The nature of the competing warfighting characteristic objectives are compatible with the principles of linear goal programming. Consequently, an effort was undertaken to develop a tool (EFFORT) which planners and analysts could use to help develop force packages.

a. The purpose behind the development of EFFORT was to have a tool which gave analysts and planners the ability to rapidly develop force packages which could achieve certain performance goals. Instead of doing iterations of a time-consuming constructive simulation,

EFFORT can be used to find the optimal force package based on current constructive simulation results. Additionally, EFFORT has the following characteristics.

(1) The program incorporates the warfighting characteristic FSC of units. EFFORT considers the lethality, survivability, deployability, sustainability, and tempo of companies, batteries, and troops. If required, additional FSC can be developed. Furthermore, although companies, batteries, and troops are the units used in EFFORT, the program can be modified to work with either individual systems or higher echelon units (battalions and brigades).

(2) EFFORT is adaptable to any scenario, environment, or force year (for analysis in NEA, SWA, or any other geographical region and for current or future operations). Instead of designing a model specified for only one type of conflict, the model is robust enough to accept a variety of conditions. This approach permits unit capability to vary as it would in real world situations. For example, a light infantry company will be more lethal in a jungle environment rather than a desert environment.

(3) The model uses output from constructive simulations. EFFORT is not tied to a particular constructive simulation and can use either high-resolution or low-resolution combat model results.

(4) An important feature is the ability for planners and analysts to examine "what-ifs." For example, a division commander may have already determined his deployable force package based on aircraft availability. If the division is given additional aircraft, EFFORT could be used to determine which additional units are recommended to enhance the existing force package.

(5) EFFORT is fast. It can produce a recommended force package within 90 minutes. This recommended force package can then be modified, if necessary. It provides a quick start for the commander's staff (or analysts) in determining the optimal force package based on commander guidance and intent.

b. EFFORT is modeled using the General Algebraic Modeling System (GAMS). GAMS is a state-of-the-art mathematical programming package which allows concise, easy-to-read algebraic statements and uses the XA solver for solving the linear goal program.

c. Two possibilities were considered in the goal programming approach: preemptive or nonpreemptive. The nonpreemptive approach was chosen for the following reasons.

(1) A preemptive approach is used when there is a strict hierarchy of priority levels for the goals. For example, if the deployability FSC were considered the goals of primary importance, then these FSC would receive first-priority attention. This implies that the deployability goals are clearly far more important than the other warfighting characteristic FSC. An optimal solution is first found with respect to the deployability FSC, and if there are optimal solution ties, then the second-priority goals are considered. If there are still ties, then the third-priority goals are considered, and so on. Although an argument can be made that the warfighting characteristics of

lethality, survivability, deployability, sustainability, and tempo can have a hierarchy of priority levels, most planners would not favor one warfighting characteristic completely over the others.

(2) A nonpreemptive goal program approach is used when the FSC goals are considered to be of roughly comparable importance, which is the case with warfighting characteristics and FSC. The most one FSC goal can be favored over another goal is 7.5 times as much. By having all of the FSC goals with roughly comparable importance, no single FSC is omitted when finding the optimal solution. Consequently, the nonpreemptive approach was selected as the modeling approach.

d. Linear goal programming has three basic steps: establishing the numeric goal for each objective, formulating an equation for each objective, and then solving to minimize the weighted sum of deviations between each of the objective functions and their goals.

(1) Establishing numeric goals. EFFORT allows the planner or analyst to change the desired goals of the force based on METT-T and other variables. The ability to change the goals is vital to the program's robustness. For example, the analyst can see how the force package changes if the lethality FSC of destroying threat tanks is raised from 300 to 400.

(a) Another consideration is that priorities and requirements of the force desired by the decision maker are subject to change. The force will have different warfighting characteristic capabilities in response to different geographical regions and threats; therefore, the ability to change goals is important.

(b) The user can change the FSC goals of the force as necessary to represent the scenario. The FSC goals are those listed in figure 4. An interesting point arises with the survivability FSC where the user must determine the percentage (or number) of friendly systems to survive. Certainly battlefield commanders do not want any casualties, but risk is inherent in any military operation, and the user must decide what the acceptable risk is in terms of a goal.

(c) The commander (or analyst) must specify their desired goals for the force. These goals are stated explicitly allowing staff elements to examine the goals and give recommendations to the decision maker. Instead of the commander (or analyst) giving vague, general guidance for the force goals, he must now clearly state the FSC goals. These goals can then be adjusted to determine the effect on the force.

(d) An important concept pertaining to the goals is that the goals should be roughly the same in relative magnitude. This prevents one goal from dominating the composite objective function. The following example shows why keeping the goal magnitude similar is important.

1. The force may have a FSC goal of destroying at least 200 threat tanks and a FSC sustainability goal of using no more than 70,000 gallons of fuel. These two FSC goals form the right-hand sides of the constraint equations.

2. Assume that both FSC goals are given an importance weight of 2 (meaning that for each deviation from the goal, the objective function suffers an importance weight of 2). If the force only destroys 150 threat tanks (50 tanks short of the specified goal), the objective function is 100 [(goal of 200 tank kills - actual kills of 150) x importance weight of 2]. Similarly, if the force uses 70,050 gallons of fuel (50 gallons over the specified goal), the objective function is also 100 [(actual gallons of 70,050 - goal of 70,000 gallons) x importance weight of 2].

3. Although both FSC goals deviations resulted in an deviation value of 100, there was a significant difference in the goal accomplishment. The force achieved only 75% of its lethality FSC goal, but only exceeded the FSC sustainability goal by less than one-tenth of 1%. However, the deviation value of 100 was the same in both cases.

4. Preventing this undesirable deviation value dominance is accomplished by multiplying or dividing the constraint equations by an appropriate scaling factor. For example, the fuel FSC constraint could have been divided by the scaling factor of 140. If this is done, then the lethality FSC goal still has an overall deviation value of 100, but now the overall deviation value of the sustainability FSC goal is approximately .71 [((actual gallons of 70,050 - goal of 70,000 gallons) x importance weight of 2) divided by 140].

5. These overall deviations are more representative of the actual force performance. As the goal program algorithm is solving, it will try to improve the force's capability in destroying threat tanks because not achieving this FSC goal causes an increase in the objective function that the goal program is trying to minimize. This approach makes intuitive sense because emphasis should be placed on the weakest FSC; namely, the lethality FSC goal which was short of its intended goal by 25%.

(d) With the goals specified, the next step is to determine the contribution of each unit in achieving these goals.

(2) Formulating objective functions. Each unit impacts, to some extent, on each of the FSC goals. The requirement is to determine how to measure this impact for each unit.

(a) For certain FSC goals, this information is readily available. For example, the deployability FSC of determining the number of C141 and C5 airplanes required by each type of unit is obtained from the data bases of the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA). Similarly, sustainability FSC of how much fuel and ammunition a unit requires depending on the type of operation and nature of the battle is available from TRAC-Fort Lee.

(b) Evaluating the effectiveness of units for lethality, survivability, and tempo FSC is not as easy. Data are readily available to measure the effectiveness of individual weapon systems, but this data will not be of extensive use when assessing the capabilities of an entire unit. Furthermore, the synergism present both within and between units also influences the units' effectiveness. One approach is to generate a series of combat model runs and then average these

results to measure each unit's contribution (deterministic), while another approach is to do the same runs and evaluate the probability distribution for the unit's contribution (stochastic). EFFORT uses a modified stochastic approach to account for the variability associated with unit capabilities.

(c) EFFORT utilizes a linguistic application of fuzzy set theory to capture the contribution of units. The use of fuzzy sets implicitly handles the nonlinearity inherent with unit synergism and avoids having to formulate and solve a much more difficult nonlinear goal program.

1. Each unit has its contribution measured using the fuzzy linguistic variables of *high, moderately high, medium, moderately low,* or *low*. The numerical ranges associated with these fuzzy sets are different for each of the FSC, but the linguistic terms remain the same.

2. Since synergism of units is present and the number of combat model runs is limited, fuzzy sets are used to capture the associated imprecision. For example, although a unit may be assessed as *moderately high* in destroying threat tanks, fuzzy set theory allows for the possibility that its numerical range falls in the range associated with the *high* or *medium* linguistic terms.

3. The advantage of this approach is that users can more readily assess units using linguistic terms rather than precise numbers. The user can adjust the range of values for the fuzzy sets or change the linguistic term assigned to a unit. An excellent example is for a light infantry company. Although its lethality contribution may be *low* in desert scenarios, its contribution may be *high* in a jungle or mountainous scenario. Again, the ability of the user to change the characteristics associated with the units provides a useful and appealing tool for decision makers.

4. An example using the fuzzy set methodology to determine unit contributions to FSC is presented to help clarify the actual procedure.[4] Assume that the lethality FSC of destroying threat tanks is being examined.

a. A funnel fuzzy set is used. In this approach, the ranges are the largest for *high* and smallest for *low*, since there is more variability for the units which are most lethal, most survivable, and have the best tempo. Within the ranges for the linguistic terms of *high, moderately high, medium, moderately low,* and *low,* a uniform distribution is used because each value has the same probability of occurring. Figure 10 shows a sample funnel fuzzy set and the overlap among linguistic variables.

---

[4] The author thanks Cadet James Tuite and Cadet Bart Johnke of the United States Military Academy at West Point for their assistance in the application of this methodology during their Individual Academic Development (IAD) Summer Internships.

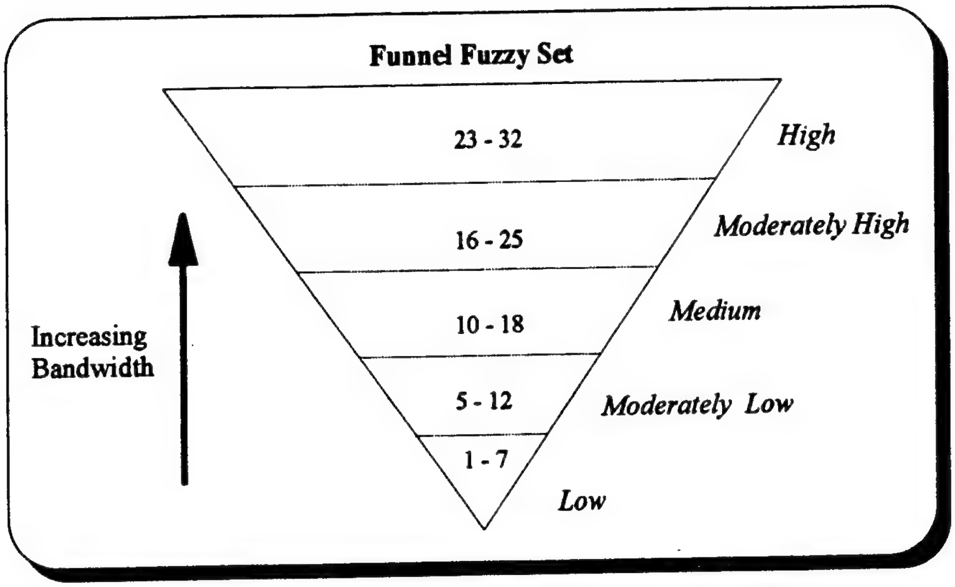


Figure 10. Funnel Fuzzy Set

b. Constructive simulation runs from the desired geographical region and approximate force year are conducted. Previous constructive simulation results can be used (provided they focus on the same geographical region and force year). Using previous runs is the preferred method due to the time savings. A minimum of three runs is desirable. Although the force packages are different for each run, the purpose is to determine the average, relative contribution of a unit type with respect to a geographical region and approximate force year.

c. The total kills for each unit type are collected and divided by the number of units of that type in the force package. This is performed for each run. The highest, lowest, and average kills of each unit type is then calculated. For instance, assume that there are three runs being examined for an MLRS battery. In the first run, there were two MLRS batteries that killed a total of 38 threat tanks (which means an MLRS battery in this run killed an average of 19 threat tanks). In the second run, there was one MLRS battery which killed 22 threat tanks. In the third run, there were three MLRS batteries which killed 84 threat tanks (meaning an MLRS battery in this run killed an average of 28 tanks). From these three runs, the MLRS battery contribution is represented by the high value of 28, the low value of 19, and the average of 23. Although whole numbers are used in this example (preferred), percentages can also be used.

d. The individual runs are subsequently examined to determine the single highest contribution from all unit types. This single highest contribution is then multiplied by 1.05, and this result is rounded up to become the upper bound for *high*. For example, if the highest value for all unit types for all runs was 30 threat tank kills, then the upper bound for *high* becomes 32. This additional 5% margin allows for the possibility that units with a linguistic rating of *high* might perform marginally better than what was

observed in constructive simulations. This 5% margin is a judgment value based on experience and can be changed by the user. The lower bound for *low* is always 1.

e. The difference between the upper bound of *high* and the lower bound of *low* is calculated and divided by 5 (the number of linguistic terms). If the quotient is not an integer, the result is rounded down. This resultant is added to the lower bound of *low* and becomes the upper bound of *low*. For example, if the upper bound of *high* was 32, then (32-1)/5 = 6.2. Rounding down this result to the nearest whole number yields 6, and adding this to the lower bound of *low* gives 7. The range for the *low* is then 1 to 7.

f. The overlap of 2 between linguistic terms can be changed by users. This overlap then specifies the lower bound of *moderately low* as 5 [7 (upper bound of *low*) - 2 (overlap)]. To establish the upper bound of *moderately low*, add 1 (standard additive factor, again which can be changed by the user) to 6 (original rounded quotient) to get a range band width of 7. Adding this to 5 gives the upper bound of *moderately low* of 12. The range for *moderately low* is then 5 to 12.

g. The lower bound for *medium* is then 10 [12 (upper bound of *moderately low*) - 2 (overlap)]. The upper bound is the new range band width of 8 [1 (standard additive factor) + 7 (range band width of *moderately low*)] added to the lower bound of 10 to give the *medium* upper bound of 18. *Medium* then has the range of 10 to 18.

h. The lower bound for *moderately high* is 16 [18 (upper bound of *medium*) - 2 (overlap)]. The upper bound is the new band range width of 9 [1 (standard additive factor) + 8 (range band width of *medium*)] added to the lower bound of 16 to give the *moderately high* upper bound of 25. *Moderately high* has the range of 16 to 25.

i. The lower bound for *high* is 23 [25 (upper bound of *moderately high*) - 2 (overlap)]. The upper bound (previously determined) is 32 to give *high* the range of 23 to 32. Although *moderately high* and *high* have the same range bandwidth, the funneled range bandwidth effect is still maintained. The reason for the same width is due to the rounding, but it does not hinder the effectiveness of the fuzzy sets.

j. The unit is subsequently assigned a fuzzy linguistic term for its capability in destroying threat tanks based on where its average from the constructive simulation runs falls within the range bands. Consideration also needs to be given to the high and low values of the unit type. For example, the MLRS battery killed an average of 23 threat tanks with a high value of 28 kills. The user may decide to assign a linguistic term of *high* even though the average falls in the *moderately high* band. If the user assumes that the constructive simulations were not an accurate representation of a unit's capability, the linguistic term can be subjectively upgraded or degraded.

k. This procedure applies for the lethality, survivability, and tempo FSC. The pseudorandom number generator (RNG) of GAMS generates the actual value used from the specified numerical ranges of the linguistic variables.

(3) Minimizing sum of deviations. Prior to seeking a solution that minimizes the weighted sum of deviations from the FSC goals, two further specifications can be made.

a. For each unit type, the user can set the lower bound (minimum) and upper bound (maximum) for the number of the unit type to include in the goal program solution. This allows the decision maker to make up-front choices about the unit types and quantities to be in a force package. This capability allows the user to either ensure a certain unit is included or excluded from the solution or limit the maximum number of units to those that are available or exist.

b. The decision maker must also assess the importance of achieving each of the FSC goals. Fuzzy sets are not required for these importance assignments because the decision maker is dictating the weighting requirements just as he dictated the goals (also non-fuzzy).

1. The non-fuzzy terms used for the importance assessment are *most important, more important, important, less important, least important,* and *not important*. For instance, the decision maker might assess the lethality FSC goal of destroying threat tanks as *most important* and the sustainability FSC goal of fuel usage as *least important*.

2. Again, the decision maker must make these choices explicitly to support the modeling process. Although decision makers currently consider these factors, they usually do so implicitly. By making explicit choices, planners and analysts are better able to understand the decision maker's intent.

3. The rationale for utilizing these non-fuzzy terms is to make it easier for the decision maker to express his desires. It is inherently difficult to have a decision maker quantitatively assess one goal relative to another (e.g., 2.37 times as important as another) so the linguistic procedure was adopted. The GAMS' RNG is also used to assign representative values for these non-fuzzy importance terms. Table 1 shows the scale used to bound and represent the importance terms. If desired, the weight ranges can be adjusted by the user.

Table 1. Importance Terms

Term	**Weight Range**
most important	6.01 - 7.5
more important	4.51 - 6.0
important	3.01 - 4.5
less important	1.51 - 3.0
least important	.10 - 1.5
not important	0

e. The essential algebraic constraints in linear goal programs involve auxiliary variables and their associated positive and negative components. Each of the FSC goals (constraints) have their auxiliary variable and positive and negative components incorporated into the overall objective function. The following example will clarify how the goal programming is performed to aid in the development of force packages.

(1) Assume that the lethality FSC goal of destroying threat tanks (greater than or equal to constraint) is:

$$12x_1 + 10x_2 + 15x_3 \geq 200. \tag{1}$$

This represents that each unit of type x_1 is expected to destroy 12 threat tanks; each unit of type x_2 is expected to destroy 10 threat tanks; and each unit of type x_3 is expected to destroy 15 threat tanks. Remember that these expected values are from the derived fuzzy sets, and the actual coefficients used in the constraint are generated by GAMS' RNG. The goal is to destroy at least 200 threat tanks. Assume the penalty weight (used in a later step) for each threat tank under 200 not destroyed is 2.

(2) Assume that the deployability FSC goal of C141 aircraft (less than or equal to constraint) is:

$$10x_1 + 5x_2 + 8x_3 \leq 600. \tag{2}$$

This represents that each unit of type x_1 requires 10 C141 aircraft to deploy; each unit of type x_2 requires 5 C141 aircraft; and each unit of type x_3 requires 8 C141 aircraft. These values are deterministic. The goal is to deploy with less than 600 C141 airplanes. Assume that the penalty weight (again, used in a later step) for each C141 aircraft used over 500 is 3.

(3) The new auxiliary variables are created from these constraint equations. Equation (1) becomes:

$$y_1 = 12x_1 + 10x_2 + 15x_3 - 200. \tag{3}$$

Equation (2) is created in a similar manner and becomes:

$$y_2 = 10x_1 + 5x_2 + 8x_3 - 600. \tag{4}$$

(4) The auxiliary variables are separated into their positive and negative components. The variable y_1 is now equal to:

$$y_1 = y_1^+ - y_1^-. \tag{5}$$

The variable y_2 is equal to:

$$y_2 = y_2^+ - y_2^-. \tag{6}$$

The positive and negative components of y_1^+, y_1^-, y_2^+, and y_2^- are all greater than or equal to zero.

(5) There is no penalty for destroying more than 200 threat tanks so only y_1^- appears in the objective function. There is no penalty for deploying with fewer than 600 C141 aircraft so only y_2^+ appears in the objective function. The penalty weights for the associated FSC goal are multiplied by these components (positive or negative) and summed to determine the objective function's value. When solving the goal program, the intent is to minimize the objective function value because this means the force is close to accomplishing its FSC goals. Recalling that the penalty weights were 2 for lethality and 3 for deployability, the formulated linear program of this goal programming problem is:

$$\text{Minimize} \qquad Z = 2y_1^- + 3y_2^+ \tag{7}$$

$$\text{subject to} \qquad 12x_1 + 10x_2 + 15x_3 - (y_1^+ - y_1^-) = 200 \tag{8}$$

$$\tfrac{1}{3}[10x_1 + 5x_2 + 8x_3 - (y_2^+ - y_2^-)] = (600)(\tfrac{1}{3}) \tag{9}$$

$$x_1, x_2, x_3, y_1^+, y_1^-, y_2^+, \text{ and } y_2^- \geq 0. \tag{10}$$

(6) As previously explained, equation (9) has been multiplied by a scaling factor to prevent any single FSC goal from dominating the objective function. This reformulated problem can then be encoded and solved using standard mathematical programming techniques.

f. Specifically, EFFORT is modeled in GAMS and solved with the XA solver. The linear program formulated from equations (1) through (10) is represented in the algebraic language of GAMS.

(1) The auxiliary variables are represented in GAMS as:

```
SLACK(CONSTRAINT) =E= POS_SLACK(CONSTRAINT) -
NEG_SLACK(CONSTRAINT).
```
(11)

Equations (5) and (6) use equation (11) to separate the auxiliary variables (SLACK) into their positive (POS_SLACK) and negative (NEG_SLACK) components. This shows the advantage of GAMS' algebraic language. Instead of writing individual auxiliary variable equations for each

FSC goal (CONSTRAINT), one algebraic statement in GAMS can represent numerous auxiliary variable equations.

(2) The constraint equations are represented in GAMS as:

SUM(UNIT_TYPE, COEF(UNIT_TYPE, CONSTRAINT) *
NUMBER(UNIT_TYPE)) -SLACK(CONSTRAINT) =E=
CNST_DATA(CONSTRAINT, "LIMIT"). (12)

Equations (8) and (9) use equation (12) to represent the constraints in the reformulated linear program. The left-hand side of the constraint equation has each of the unit types multiplied by their expected contribution to the FSC goal and by the total number of that unit type in the force package. This product has the positive and negative components of the auxiliary variable subtracted from it. The right-hand side of the constraint equation is the FSC goal. Again, this one algebraic statement in GAMS represents each of the constraint equations for the FSC goals.

(3) The objective function is represented in GAMS as:

OBJ =E= SUM(CONSTRAINT, CNST_DATA(CONSTRAINT,
"WEIGHT") *(POS_SLACK (CONSTRAINT) $(CNST_DATA
(CONSTRAINT, "SIGNS") GT 0) + NEG_SLACK(CONSTRAINT)$
(CNST_DATA (CONSTRAINT, "SIGNS") LT 0))). (13)

Equation (7) uses equation (13) to depict the objective equation. Equation (13) incorporates the importance weights (WEIGHT) as the penalties. For example, if the force fails to destroy less than the goal of threat tanks, then its negative component (NEG_SLACK) is used in the objective function. Conversely, if the force exceeds the goal of C141 airplanes for deployment, then its positive component (POS_SLACK) is used in the objective function.

g. Equations (11) through (13) are the specific GAMS algebraic statements which reformulate the goal programming problem into a linear programming problem. Additional constraints may be used to address associated command and control and logistical requirements.

(1) For example, constraints are included to ensure that equivalent unit types of more than two companies, batteries, and troops are given a battalion or squadron headquarters. The analogous constraint principle is used for all echelons of command (battalion, brigade, division, and corps).

(2) Additionally, constraints are incorporated to ensure CSS maintenance units are included in the force package. For example, since attack helicopter companies require maintenance assets, logistical rules are modeled as constraints to force the inclusion of the required resources for aviation. This prevents inclusion of only combat units in the force package by ignoring the logistical requirements.

(3) As previously stated, EFFORT designs a force package with combat, CS, and CSS units. Certain units (e.g., chaplain section, veterinary detachment) do not have specific constraint equations, but must be included in the force package. The preferred method to ensure that these units are included is to specify their minimum number (lower bound) as 1 and their maximum number (upper bound) as 1. This not only ensures these units are in the force package, but also incorporates their effects on the warfighting characteristic FSC of survivability, deployability, sustainability, and tempo.

h. With the formulation complete, EFFORT is solved in GAMS using the XA solver. Since EFFORT is stochastic (the fuzzy set representation of certain FSC goals and the importance weights), the RNG seed is changed prior to each solve iteration. A further issue relates to how many iterations are needed to obtain a satisfactory solution.

(1) One of the problems with stochastic models is the time required to complete a sufficient number of runs to satisfy the alpha and beta statistical testing criteria. Instead of mandating a certain number of runs, an alternate approach has been used.[5]

(2) The procedure for conducting the runs typically takes less than 90 minutes on personal computers with a pentium processor and minimum operating speed of 90 megahertz. The procedure is outlined below to clarify the stopping criteria.

(a) The user performs 25 runs of EFFORT, changing the random number seed each time. The results for each unit are then arranged from lowest to highest by the user.

(b) The user examines the median value (13th) and the mode for each unit type. If the median and mode are the same and no other dominant value exists (meaning 10 or more occurrences of some other value), then this number (median, mode) is the recommended number for that unit type to include in the force package.

(c) If these unit stopping criteria are not met after the 25 runs, then the user sets the number for those unit types that meet the stopping criteria. An additional 25 iterations are then performed.

(d) As before, the median and mode are examined for each of the remaining units to see if they are equal. This process is repeated until each unit type has a recommended number in the force package. Experience with EFFORT has shown that no more than 50 runs are necessary.

(e) This alternate run methodology is used because when statistical analysis for terminating simulations (steady-state) and confidence intervals are done, it usually involves only one measurement of interest (e.g., expected average delay or expected average cost). In EFFORT, there are multiple measurements of interest; namely, the number in the force package for each unit type. This problem with numerous measures is known as the multiple-comparisons problem. If multiple measures (more than 10) are needed and confidence intervals are done, then one or more

[5] The author thanks COL Thomas Pawlowski III, Ph.D. and Dr. Michael Anderson for their insight into this question.

of the confidence intervals will probably not contain its true measure. Furthermore, EFFORT requires integer solutions for the number of each unit type to include in the force package. The alternate methodology used in EFFORT sufficiently addresses the multiple-comparisons problem and integer solution requirement.

i. After EFFORT arrives at a solution, the results are imported into a spreadsheet. The spreadsheet shows the unit type name and the number of that unit type recommended from each iteration. The median and mode analysis can then be completed using the spreadsheet. Table 2 illustrates a sample output for five iterations of EFFORT and a partial listing of four units.

Table 2. Sample EFFORT Output

Unit Type	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
Light Infantry Co	6	5	6	8	7
M1 Co	4	3	4	5	4
Corps MP Co	2	2	1	1	1
Chaplain Detachment	1	1	1	1	1

j. EFFORT determines the overall objective function (sum of all the deviations from FSC goals). This allows the analyst or planner to determine which force package is best (based on the force package with the lowest objective function value). A shortcoming of EFFORT is that it cannot determine whether the force will win or lose; instead, it tells the user the total deviation from the goals. It is assumed that if the developed force package is close to achieving the FSC goals, then it can be expected to win. The FSC goal values are those goals which the force should accomplish in order to be successful. If the force accomplishes or nearly accomplishes these FSC goals, then the force should win (whether in real-world or simulations).

k. Although EFFORT calculates the sum of all deviations from FSC goals during its solution process, examination of the individual FSC goals is also possible. This allows the analyst to determine which FSC are furthest from their goals and identify possible weaknesses in the proposed force package.

l. EFFORT has been designed to derive force packages based on desired goals' accomplishments. EFFORT can also determine how far a proposed force package deviates from its goals (the approach used in the WFLA 98-12 Force Package Analysis).

(1) Instead of letting EFFORT determine how many of each unit type to include, the number of units is set by the user. For example, if the force package has two MLRS batteries in it, then the lower and upper bound is set at two units (this ensures that two, and only two, MLRS batteries are in the force package). This is repeated for all unit types.

(2) The FSC goals and importance weights are entered as previously explained.

(3) EFFORT is now run 50 times (experience shows 50 runs is sufficient, but no extensive steady-state statistical analysis has been conducted). The objective function (total deviation from goals) is captured and averaged. This value is then used to compare its performance with other proposed force packages. Alternatively, analysis of individual FSC goals can be performed to determine which force packages are best for accomplishing specific goals.

m. EFFORT is programmed using modules (similar to subroutines). Modules can be omitted or included, based on need. New modules (e.g., new warfighting characteristic FSC) can be built and incorporated into the main program easily. The modular structure of EFFORT is also beneficial during debugging and explanation to novice users.

n. The requirement for a knowledge of GAMS and writing of algebraic statements is a limitation of EFFORT. There is no graphical user interface (GUI); instead, the user must type all entries. Discussions with the GAMS Development Corporation indicate that Visual Basic is compatible with GAMS and could be used in a GUI design.

o. In summary, EFFORT can be used for two primary purposes: to identify a force package most capable of meeting the FSC goals or to assess a specified force package's capability in meeting FSC goals. EFFORT allows users to adjust the following parameters:

- minimum and maximum number of a particular unit type in a force package,
- assessment (using linguistic application of fuzzy set theory) of warfighting characteristic FSC of unit types,
- relative importance (using the importance weights) of the warfighting characteristic FSC, and
- desired FSC goals for the force package to accomplish.

10. **THOR.** THOR's purpose is to assist analysts and planners in task-organizing their available force to accomplish its mission(s) against a specified threat. THOR is an extension and modification of EFFORT.

a. EFFORT is designed for the strategic and operational levels to identify force packages for deployment to a specific region and to engage a specific threat. THOR is designed for the operational and tactical levels, assisting in the task-organization of the available force. Essentially, EFFORT can identify the force package to deploy, and THOR can task-organize that force package to best "match-up" against an enemy. THOR uses the same goal programming, fuzzy set theory, and stochastic principles as EFFORT.

b. The DCG, TRADOC, believed the Force Tailoring Tools would be of benefit to the BCE MSF Commander. Acting upon his guidance, the tool was demonstrated to the MSF Commander of the BCE (U.S. Army brigadier general). EFFORT was modified to become THOR. THOR proved successful during two simulation exercises and PW95 while assisting the MSF Commander in task-organizing his available force.

c. There are four significant programming differences between THOR and EFFORT.

(1) THOR provides a more explicit representation of goals. For example, assume that a force has two mission requirements: a movement to contact against three threat mechanized infantry regiments and a deliberate attack against two threat tank regiments. EFFORT requires one lethality FSC goal of destroying threat tanks, while THOR will use two FSC lethality goals. One FSC goal relates to destroying the threat tanks in the mechanized infantry regiments while the other FSC goal relates to destroying the threat tanks in the tank regiments. The FSC goals must be determined for each different mission the force is required to do.

(2) The importance weights are specified for each FSC goal (and need not be the same). In the previous example, destroying threat tanks in the tank regiments may be weighted as *most important*, but when considering the mechanized infantry regiments, the goal may be weighted as *important*.

(3) The unit type variable names need to be expanded in THOR. In EFFORT, the unit type of "MLRS" (to represent an MLRS battery) was sufficient, but in THOR, this naming convention will not work because it does not specify where the MLRS batteries fight. For the previous example, the unit type "MLRS-MR" specifies the number of MLRS batteries fighting the mechanized infantry regiments, and "MLRS-TR" specifies the number of MLRS batteries fighting the tank regiments.

(4) Additional constraints are required to ensure that no more than the available number of unit types are used. For example, if the force package had an MLRS battalion (three batteries) available, then the GAMS constraint is written as:

$$\text{"MLRS-MR"} + \text{"MLRS-TR"} \quad \text{=E=}\ 3. \tag{14}$$

Equation (14) ensures that each of the three MLRS batteries are used. Subsequently, THOR determines how best to task-organize the unit types to accomplish the FSC goals.

d. In summary, THOR can be used for two primary purposes: to identify how a force should be task-organized to meet the FSC goals or to assess a specified task-organization's capability to meet the FSC goals. THOR allows users to adjust the following parameters:

- minimum and maximum number of a unit type to be used for each mission,
- assessment (using linguistic application of fuzzy set theory) of warfighting characteristic FSC of unit types for each mission,
- relative importance (using the importance weights) of the warfighting characteristic FSC for each mission, and
- desired FSC goals for the force to accomplish for each mission.

11. **Conclusions.** The Force Tailoring Tools utilize several operations research techniques: fuzzy set theory, artificial intelligence, linear programming, and stochastic modeling. Although these are not new techniques, they combine to offer a new direction for force design analysis.

These operations research techniques, when used concurrently, may have applicability for other military applications.

a. The Force Tailoring Tools are not designed to replace military commanders or challenge the art of command, but are designed to assist in decision making. The tools serve as decision aids for commanders, military planners, and analysts and should not be construed as giving the preferred solution that must be adopted. The tools offer an analytical methodology to help in difficult and critical force design issues.

b. The Force Tailoring Tools continue to be upgraded and refined throughout the various study efforts. New FSC are constantly being evaluated for inclusion into the tools. Although the Force Tailoring Tools have been used exclusively to evaluate U.S. Army forces, the tools could be used for joint and combined analysis. The Force Tailoring Tools are currently being evaluated for use in the Joint Close Support End-to-End Assessment in support of J-8 (Joint Staff Force Structure Resources and Assessment).

c. Force XXI principles address the new dimensions of warfare that require quick and lethal forces adaptable to changing environments. The Force Tailoring Tools assist military planners and analysts in force design and force tailoring by identifying the optimal force for a given geographical region and threat.

APPENDIX A

REFERENCES

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX B

GLOSSARY

THIS PAGE INTENTIONALLY LEFT BLANK.

Appendix A
Force Tailoring Tools
References

CLIPS User's Guide, Dr. Joseph Giarratano, NASA, Lyndon B. Johnson Space Center, Informations Systems Directorate, Software Technology Branch, September 1991.

Early Entry Force Analysis Final Report, COL Thomas Pawlowski, MAJ David Rodgers, CPT Thomas Cioppa, and Carol Mullen, Technical Report TRAC-TR-1494, Fort Leavenworth, Kansas, September 1994.

Fuzzy Expert Systems, Abraham Kandel, CRC Press, Boca Raton, Florida, 1992.

GAMS: A User's Guide, Anthony Brooke, David Kendrick, and Alexander Meeraus, The Scientific Press, San Francisco, California, 1992.

Introduction to Operations Research, Frederick Hillier and Gerald Lieberman, McGraw-Hill Publishing Company, New York, 1990.

Linear Programming and Network Flows, Mokhtar Bazaraa, John Jarvis, and Hanif Sherali, John Wiley and Sons, New York, 1990.

Mission Essential Task List (METL) Assessment Using A Linguistic Application of Fuzzy Set Theory, CPT Thomas Cioppa, Naval Postgraduate School, Monterey, California, September 1994.

Mobile Strike Force 95 Organizational and Operational Analysis, Timothy Bailey, Roland Groover, CPT Thomas Cioppa, CPT Brendan Sheehan, and Carol Mullen, Fort Leavenworth, Kansas, January 1996.

Simulation Modeling and Analysis, Averill Law and W. David Kelton, McGraw-Hill Publishing Company, New York, 1991.

TRADOC Pam 525-71, *Force XXI Division Operations Concept (Draft)*, June 1995.

Warfighting Lens Analysis 98-12 Force Package Analysis, CPT Thomas Cioppa, Fort Leavenworth, Kansas, December 1995.

THIS PAGE INTENTIONALLY LEFT BLANK.

Appendix B
Force Tailoring Tools
Glossary

AFV	armored fighting vehicle
BCE	Battle Command Elective
BLITCD	Battle Laboratory Integration, Technology, and Concepts Directorate
CGSC	Command and General Staff College
CLIPS	C Language Integrated Production System
CS	combat support
CSS	combat service support
DCG	Deputy Commanding General
EEA	essential elements of analyses
EEFA	Early Entry Force Analysis
EELS	Early Entry Lethality and Survivability
EFFORT	Early Entry Force Tailoring Tool
EPP	extended planning period
Force-PLUS	Force Package Logic Utility System
FSC	force sufficiency criteria
FY	force year
GAMS	General Algebraic Modeling System
GUI	graphical user interface
HQ	headquarters
IAD	Individual Academic Development
J-8	Joint Staff Force Structure Resources and Assessment
LAM	Louisiana Maneuvers
METT-T	mission, enemy, troops, terrain and weather, and time available
MLRS	multiple-launch rocket system
MSF	Mobile Strike Force
MTMCTEA	Military Traffic Management Command Transportation Engineering Agency

NEA	Northeast Asia
O&O	Organizational and Operational
POM	programmed objective memorandum
PW	Prairie Warrior
SCRAP	Sufficiency Criteria for Realignment Adjustment Processor
SME	subject matter expert
SWA	Southwest Asia
THOR	The Task Organizer
TRAC	Training and Doctrine Command Analysis Center
TRADOC	Training and Doctrine Command
WFLA	Warfighting Lens Analysis

APPENDIX C

DISTRIBUTION LIST

THIS PAGE INTENTIONALLY LEFT BLANK.

Appendix C
Force Tailoring Tools
Distribution List

	No. Copies
Defense Technical Information Center ATTN: DTIC-TCA Cameron Station Alexandria, VA 22314	1
US Army Library Army Study Documentation and Information Retrieval System (ASDIRS) ANRAL-RS ATTN: ASDIRS Room 1A518, The Pentagon Washington, DC 20310	1
US Army Combined Arms Research Library (CARL) ATTN: ATZL-SWS-L Fort Leavenworth, KS 66027	1
HQDA ATTN: SAUS-OR The Pentagon Washington, DC 20310	1
HQ, TRADOC EELS Battle Lab ATTN: ATCD-L Fort Monroe, VA 23651-5000	1
HQ, TRADOC BLITCD ATTN: ATCD-B Fort Monore, VA 23651-5000	1
Commander, US Army Aviation Center ATTN: ATZQ-CDO Fort Rucker, AL 36362-5000	1

	No. Copies
Commandant, US Army Field Artillery School ATTN: ATSF-CBL Fort Sill, OK 73503-5600	1
Commander, US Army Combined Arms Center ATTN: ATZL-CAC Fort Leavenworth, KS 66027	1
Commander, US Army Combined Arms Support Command ATTN: ATCL-C Fort Lee, VA 23801-6200	1
Commandant, US Army Air Defense Artillery School ADA Center - Force Development and Analysis Fort Bliss, TX 79916-7000	1
Commandant, US Army Engineer School ATTN: ATFE-CD-SIM Fort Leonard Wood, MO 65473-5331	1
Commandant, US Army Infantry School ATTN: Force XXI, CATD Fort Benning, GA 31905-5007	1
Commandant, US Army Chemical School ATTN: ATZN-ZN-CMC-C Fort McClellan, AL 36205-5020	1
Commandant, US Army Military Police School ATTN: ATZN-MP Fort McClellan, AL 36205-5030	1
Commandant, Army Logistics Management College ATTN: ATSC Fort Lee, VA 23801-6040	1
Commandant, US Army Command and General Staff College ATTN: ATZL-SW Fort Leavenworth, KS 66027-5000	1
Commandant, US Army Field Artillery School ATTN: ATSF-ATF (TF2000) Fort Sill, OK 73505-5600	1

	No. Copies
Chairman, Department of Operations Research Naval Postgraduate School Monterey, CA 93943-5000	2
United States Military Academy Department of Systems Engineering West Point, NY 10996	1
Director, MTMCTEA ATTN: MTTE-OA 720 Thimble Shoals Blvd Newport News, VA 23606-2574	1
Commander, US Army Military Police School ATTN: Directorate of Training and Doctrine (Force XXI) Fort McClellan, AL 36205	1
Commander, US Army Armor Center Director, Force Development Fort Knox, KY 40121-5000	1
Director, National Simulation Center ATTN: ATZL-NSC-T Fort Leavenworth, KS 66027	1
U.S. Army Concepts Analysis Agency 8120 Woodmont Ave Bethesda, MD 20814-2797	1
U.S. Army Material Systems Analysis Activity ATTN: AMXSY-CD Aberdeen Proving Grounds, MD 21005-5071	1
U.S. Army Operational and Testing Evaluation Command Park Center IV 4501 Ford Ave Alexandria, VA 22302-1458	1

Director, USATRAC

Director, TRAC-OAC, ATTN: ATRC-F, Ft Leavenworth, KS 66027	1
Director, TRAC-WSMR, ATTN: ATRC-W, WSMR, NM 88002-5502	1
Director, TRAC-TOD, Fort Leavenworth, KS 66027	1
Director, TRAC-SWC, Fort Leavenworth, KS 66027	1
Director, TRAC-Lee, Fort Lee, VA 23801-6140	1
Director, TRAC-Monterey, Monterey, CA 93943	1
Director, TRAC-SAC, Fort Leavenworth, KS 66027	3